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DYNAMICS OF COMPOSITE MATERIALS AND ELASTIC STRUCTURAL ELEMENTS--ETC(U)
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ARO 15872.12-EG

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. A119918	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DYNAMICS OF COMPOSITE MATERIALS AND ELASTIC STRUCTURAL ELEMENTS WITH VARIABLE DIMENSIONS		5. TYPE OF REPORT & PERIOD COVERED Final Report 21 Sept. 1979- 31 March 1982
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) S. Nemat-Nasser		8. CONTRACT OR GRANT NUMBER(s) DAAG29-79-C-0168
9. PERFORMING ORGANIZATION NAME AND ADDRESS Northwestern University Evanston, Illinois 60201		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Research Office Post Office Box 12211 Research Triangle Park, NC 27709		12. REPORT DATE September 1982
		13. NUMBER OF PAGES 6
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

DTIC ELECTE OCT 6 1982 D

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

NA

18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Dynamics, composites, periodic structures, overall properties, blades

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The project was conserned with the development and exploitation of new methodologies for an effective and accurate calculation of the dynamic response and overall properties of elastic composites with periodic structures, and vibration of elastic structural components which have relatively large variations in their stiffness, mass distribution, and/or dimensions. The work accomplished is in the areas of waves in layered and fiber-reinforced anisotropic elastic composites; stability and dynamic response of rotating blades;

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20. ABSTRACT (continued)

and overall properties of composites with periodic structures. The results have been reported in nine papers, which have been (or will be) published in the scientific literature.

DYNAMICS OF COMPOSITE MATERIALS AND ELASTIC STRUCTURAL ELEMENTS WITH VARIABLE DIMENSIONS

FINAL REPORT

S. NEMAT-NASSER

September 1982

U. S. ARMY RESEARCH OFFICE

GRANT No.: DAAG29-79-C-0168

NORTHWESTERN UNIVERSITY
Evanston, Illinois 60201

A. Statement of Problem Studied

This project was concerned with the development and exploitation of new methodologies for an effective and accurate calculation of the dynamic response and overall properties of elastic composites with periodic structures, and vibration of elastic structural components which have relatively large variations in their stiffness, mass distribution, and/or dimensions. The results have immediate applications to the characterization and design of composite materials which may be used for heat shielding, dispersion of pressure pulses, and related technologies on the one hand, and on the other hand, applications to rotorcraft dynamics, vibration of plates with variable dimensions or with holes and inclusions, and other structural elements in common usage in various crafts, machineries, and control systems.

The work accomplished may be divided into three areas:

1) Waves in layered and fiber-reinforced anisotropic elastic composites;

2) Stability and dynamic response of rotating blades;

3) Overall properties of composites with periodic structures.

A total of eight papers have been completed, and a ninth is in preparation. Papers numbered (in the List of Publications) 1, 2, 3, 5, and 6 are in the first area; papers 7, 8, and 9 are in the second, and paper 4 is in the third area. The abstracts of these papers indicate the major points and contributions.

B. Summary of Most Important Results

T' e results obtained under this project are summarized in the abstracts of the completed articles, which are as follows:

1) Harmonic Waves in Layered Transversely Isotropic Composites, by S. Nemat-Nasser and M. Yamada, Journal of Sound and Vibration, Vol. 79(2), 1981, pp. 161-170:

ABSTRACT: The dispersive property of laminated elastic composites consisting of transversely isotropic layers is studied. Harmonic waves with various propagation directions with respect to the direction of layering are considered. Exact solutions are presented and compared with the results of the new quotient method recently developed by one of the authors.

2) Harmonic Waves in Fiber-Reinforced Orthotropic Elastic Composites, by S. Nemat-Nasser and M. Yamada, Journal of Applied Mechanics, Vol. 48, 1981, pp. 967-971:

ABSTRACT: The dispersive property of fiber-reinforced elastic composites consisting of orthotropic materials is studied. Based on a new quotient recently proposed by one of the authors, approximate dispersion curves are obtained, and the influence of anisotropy is illustrated.

3) Harmonic Waves with Arbitrary Propagation Direction in Layered Orthotropic Elastic Composites, by M. Yamada and S. Nemat-Nasser, Journal of Composite Materials, Vol. 15, 1981, pp. 531-542:

ABSTRACT: The dispersion of harmonic waves propagating in an arbitrary direction in a layered orthotropic elastic composite is studied. The full three-dimensional field equations of elasticity are considered, and the corresponding twelfth order characteristic determinant is examined. Numerical results are obtained and compared with the corresponding estimates of the new quotient method of Nemat-Nasser.

4) On Composites with Periodic Structure, by S. Nemat-Nasser, T. Iwakuma, and M. Hejazi, Mechanics of Materials, Vol. 1, No. 3, 1982, to appear:

ABSTRACT: The overall moduli of a composite with an isotropic elastic matrix containing periodically distributed (anisotropic) inclusions or voids, can be expressed in terms of several infinite series which depend on only the geometry of the inclusions or voids, and hence can be computed once and for all for given geometries. For solids with periodic structures these infinite series play exactly the same role as does Eshelby's tensor for a single inclusion or void in an unbounded elastic medium.

For spherical and circular-cylindrical geometries, the required infinite series are calculated and the results are tabulated. These are then used to estimate the overall elastic moduli when either the overall strains or the overall stresses are prescribed, obtaining the same results. These results are compared with other estimates and with experimental data. It is found that the model of composites with periodic structure yields estimates in excellent agreement with the experimental observations.

5) Estimate of Dynamic Properties of Composites by Mixed Finite-Element Method, by S. Nemat-Nasser, in: Hybrid and Mixed Finite Element Methods, edited by S. N. Atluri, R. H. Gallagher, and O. C. Zienkiewicz, John Wiley and Sons, in press:

ABSTRACT: Mixed variational principles provide powerful means for estimating overall properties of elastic composites. The field equations (linearized) for problems of this kind have a common feature: The differential equations involve coefficients with large variations or with discontinuities (i.e., partial differential equations with rough coefficients).

In this review article, the author summarizes the method of the new quotient (which is based on a mixed variational principle) in connection with three-dimensional elastic composites, outlines both finite-element, as well as the usual Rayleigh-Ritz approximation schemes, and gives an illustrative example.

6) Dispersion of Waves in Two-Dimensional Layered, Fiber-Reinforced, and Other Elastic Composites, by S. Minagawa, S. Nemat-Nasser, and M. Yamada, Computers and Structures (special issue in the memory of Professor K. Washizu, edited by T. H. H. Pian), in press:

ABSTRACT: Dispersion curves for waves in layered and fiber-reinforced elastic composites, and in composites of a chequerboard cross-sectional geometry, are presented. The analysis is based on two variational principles: (1) The new quotient is stationary with respect to variations of both the stress and displacement fields; and (2) the Rayleigh quotient is stationary with respect to variations of the displacement field. The computations are carried out in two ways: (a) using the finite-element method, and (b) using the exponential functions as test functions (the method of the exponential functions). The results are compared in an effort to investigate their relative accuracy and effectiveness. When the computations are carried out by the finite-element method based on the new quotient, there appear some extraneous solutions. When the Rayleigh quotient is used, no such additional solutions appear. On the other hand, the numerical results suggest that the method of the new quotient gives better estimates, as compared with those of the Rayleigh quotient.

7) Stability and Dynamic Response of Rotating Blades: A Status Report, by M. Natori and S. Nemat-Nasser, to be submitted for publication:

ABSTRACT: The present status of research on stability and dynamic response of rotary-wing aircrafts and wind energy conversion machines is examined and certain trends for future work are mentioned. Variational expressions for the problem of a single nonuniform rotating blade of a helicopter in hover and in forward flight are also presented in order to provide a better understanding of rotary-wing aeroelasticity.

8) Application of a Mixed Variational Approach to Aeroelastic Stability Analysis of a Nonuniform Blade, by M. Natori and S. Nemat-Nasser, to be submitted for publication:

ABSTRACT: The mixed variational approach is developed to investigate the coupled flap-lag-torsional aeroelastic stability of a nonuniform helicopter blade. This approach is intended to treat rotating blades with large variations or discontinuous changes in their properties. Numerical results by this approach in hovering conditions are presented for both uniform and nonuniform blades with low torsional stiffness, and compared with the results by the usual Rayleigh-Ritz method. It is clearly shown that the present approach has good convergence properties for both static equilibrium position and critical collective pitch angles.

9) On Dynamic Stability of a Helicopter Blade in Hover, by M. Natori and S. Nemat-Nasser; manuscript in preparation.

C. <u>List of Publications</u>

1. Nemat-Nasser, S. and Yamada, M., "Harmonic Waves in Layered Transversely Isotropic Composites," Journal of Sound and Vibration, Vol. 79(2), 1981, pp. 161-170.

2. Nemat-Nasser, S. and Yamada, M., "Harmonic Waves in Fiber-Reinforced Orthotropic Elastic Composites," Journal of Applied Mechanics, Vol. 48, 1981, pp. 967-971.

3. Yamada, M. and Nemat-Nasser, S., "Harmonic Waves with Arbitrary Propagation Direction in Layered Orthotropic Elastic Composites," Journal of Composite Materials, Vol. 15, 1981, pp. 531-542.

4. Nemat-Nasser, S., Iwakuma, T., and Hejazi, M., "On Composites with Periodic Structure," Mechanics of Materials, Vol. 1, No. 3, 1982, in press.

5. Nemat-Nasser, S., "Estimate of Dynamic Properties of Composites by Mixed Finite-Element Method," in: Hybrid and Mixed Finite Element Methods, edited by S. N. Atluri, R. H. Gallagher, and O. C. Zienkiewicz, John Wiley & Sons, in press.

6. Minagawa, S., Nemat-Nasser, S., and Yamada, M., "Dispersion of Waves in Two-Dimensional Layered, Fiber-Reinforced, and Other Elastic Composites," Computers and Structures (Special Issue in the Memory of Professor K. Washizu, edited by T. H. H. Pian), in press.

7. Natori, M. and Nemat-Nasser, S., "Stability and Dynamic Response of Rotating Blades: A Status Report," to be submitted for publication.

8. Natori, M. and Nemat-Nasser, S., "Application of a Mixed Variational Approach to Aeroelastic Stability Analysis of a Nonuniform Blade," to be submitted for publication.

9. Natori, M. and Nemat-Nasser, S., "On Dynamic Stability of a Helicopter Blade in Hover," in preparation.

D. Participating Scientific Personnel

Principal Investigator: S. Nemat-Nasser

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M. Yamada (from Denkitsushin University, Tokyo, Japan)
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M. Natori (from The Institute of Space and Astronautical Science, Tokyo, Japan)
August 1980 to March 1982.

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